N 62 13695

Effect of Rapid Pressure Decay on Solid Propellant Combustion

CARL C. CIEPLUCH[1]

NASA Lewis Research Center, Cleveland, Ohio

Rapid pressure decay transients were imposed on a burning, composite propellant charge by suddenly opening a chamber vent. Measurements of light emission and chamber pressure with high frequency response instrumentation indicated that pressure decay rates too low to permanently extinguish combustion could extinguish it momentarily, whereupon combustion was resumed at a steady reduced pressure. It was found that there is a minimum chamber pressure decay rate required to extinguish combustion permanently. For an aluminized composite propellant this rate was 74,000 psi/sec at an initial chamber pressure of 540 psia. The minimum rate of chamber pressure decay increased linearly as the initial chamber pressure increased. The combustion process was found to be quite sensitive to pressure decrease since it could be extinguished momentarily by pressure decay rates nearly an order of magnitude lower than required to extinguish combustion permanently.

THE ABILITY to stop and restart solid propellant rocket motors would significantly increase their flexibility and usefulness for space applications. It appears feasible that an ignition system, such as one that relies on the reaction between a hypergolic fluid and the propellant for ignition (1),[2] could be developed for the multiple ignition requirement of a restartable motor. One technique to stop the motor is to suddenly decrease the chamber pressure in order to extinguish combustion. This method has been used successfully in conjunction with ballistic missile thrust termination and as a research tool in the laboratory. With the advent of new propellants with higher impulse, however, the use of a rapid decrease in pressure to extinguish combustion completely may become more difficult.

The purpose of this investigation was to study the effect of rapid pressure decay on solid propellant combustion with a view toward a more basic understanding of the phenomenon. This article presents some of the results that have been obtained to date during investigation. Several studies along this line have been reported. In (2), observations were made of a burning strand of propellant during the sudden expansion developed by puncturing a diaphragm in the chamber. In (3), photographic studies were made of a burning strand of propellant subjected to rapid pressure decrease in a specially developed bomb. In the present investigation a propellant size and chamber combination were chosen such that the combustion environment more closely approximated that which is obtained in an actual motor, and at the same time was not so large as to lose all the simplicity and flexibility of the strand type of test. Measurements were made of combustion luminosity variation during the pressure drop and of the chamber pressure decay rate required to extinguish combustion.

Presented at the National IAS-ARS Joint Meeting, Los Angeles, Calif., June 13–16, 1961.

[1] Aerospace Research Scientist.

[2] Numbers in parentheses indicate References at end of paper.

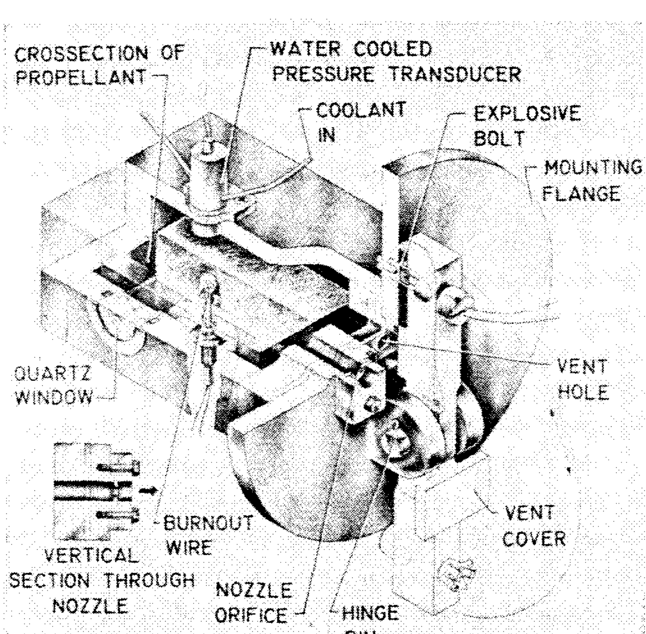

Fig. 1 Combustion chamber assembly

Apparatus and Procedure

An isometric sketch of the propellant charge positioned in the chamber is shown in Fig. 1. The propellant slab was 3-in. wide by 5-in. long by 1-in. thick. The propellant was ignited by a standard type pyrotechnic ignitor. Combustion was confined to the upper flat surface, and the chamber vent was actuated after about 3/8 in. of propellant was consumed. The propellant composition was

	Per cent by weight
Epoxy crosslinked copolymer of butadiene and a carboxylic monomer	18.8
Magnesium oxide	0.2
Ammonium perchlorate	72.0
Aluminum	9.0

The propellant had the following burning rate equation:

$$\text{Burning rate} = 0.0324\, P^{0.337} \text{ ips}$$

where P is the chamber pressure in psia.

Rapid chamber pressure decrease was obtained by suddenly opening a chamber vent hole. The vent hole cover was attached to a pivot arm (Fig. 1), which was suddenly released by an explosive bolt. The electrical signal for the explosive bolt to fire was obtained from a burn out wire which was imbedded in the propellant during casting. The chamber pressure decay rate could be varied by two different methods. One method consisted of varying the size of vent that was suddenly opened. The second method consisted of using a simple dashpot, connected to the pivot arm, which restricted the rate at which the pivot arm, and consequently the vent cover, opened. Using this technique and a large vent hole, the rate of chamber pressure decay was an inverse function of the dashpot resistance.

A quartz window located on the side of the chamber was used to view combustion across the burning surface. A small amount of nitrogen bleed was used to reduce the clouding of the window. A 0.025 to 0.030 in. molybdenum plate with a properly sized drilled hole to maintain the desired chamber pressure was used as the nozzle. The thin nozzle plate limited aluminum oxide buildup in the nozzle. The chamber was mounted by means of the mounting flange onto an altitude exhaust system equipped with an air ejector. All runs were made at an ambient pressure of 3.5 mm of mercury.

Chamber pressure was measured with a high frequency response pressure transducer which was water-cooled. Com-

(*Reprinted from* ARS JOURNAL, *November, 1961*)

bustion luminosity was measured by viewing through the quartz window with an RCA no. 5582 phototube. The tube had an S-4 response which was sensitive primarily to the visible light region with a peak sensitivity at 4000 Å. The phototube viewed a region of the flame, extending from the propellant surface up to $^1/_2$ in. above it, through a $^7/_8$-in. diam tube. The electrical output of these instruments was amplified as required and recorded on a direct recording oscillograph. Paper speed was 80 ips.

Results and Discussion

Effect of rapid pressure decay on combustion luminosity

Typical oscillograph records of combustion luminosity and chamber pressure during pressure decay transients obtained by suddenly opening the chamber vent are shown in Fig. 2. The solid line records represent a case in which the propellant continued burning after the pressure drop. For this case the chamber pressure leveled out at about 35 psia, dropping from a steady pressure of 547 psia. It is interesting to note that for this case the luminosity record decreased sharply to a minimum, which was only 7% of its original value, 0.0055 sec after the pressure decrease was initiated. This minimum luminosity point occurred at a chamber pressure of 145 psia, which was considerably above the final chamber pressure. From the minimum point the luminosity then recovered to almost its original value in 0.035 sec. This sharp drop in luminosity to almost zero during the early stages of the pressure decrease indicated that the flame was for the most part extinguished or quenched momentarily. However, the strength of the pressure drop, or in other words, the pressure decay rate, was not sufficient to prevent the flame from reestablishing at a lower pressure.

The dashed line represents the results obtained from a higher pressure decay rate (increased vent size). In this case the combustion was extinguished, and chamber pressure dropped to ambient, which was 3.5 mm of mercury, in about 0.04 sec. The luminosity record also dropped very sharply for this case. However, after an initial attempt to recover, the luminosity subsequently dropped to zero, and combustion was extinguished.

The effect of chamber pressure decay rate on the minimum luminosity during the pressure drop and luminosity recovery after the pressure drop are shown in Fig. 3. Chamber pressure decay rate was varied by varying the size of the vent. Since pressure did not vary linearly with time but was an exponential function, a representative or effective value was calculated for the pressure decay rate. It was defined as $\Delta P/\Delta t$, where ΔP was a 50% reduction in chamber pressure and Δt the corresponding time for this pressure change. At low pressure decay rates the luminosity recovered to approximately 100% of the original value, indicating combustion continued after the pressure drop. Above a pressure decay rate of about 74,000 psi/sec luminosity did not recover completely, and combustion ceased. This critical pressure decay rate for combustion extinction is probably unique for the propellant composition used in this investigation. It can be seen from the minimum flame luminosity curve in Fig. 3 that the gas phase flame is sensitive to a wide range of pressure decay rates. The flame apparently was extinguished or quenched momentarily for pressure decay rates as low as 10,000 to 15,000 psi/sec, which is almost an order of magnitude lower than that required to extinguish the flame completely. The relative sensitivity of the flame to rapid pressure decrease may be a contributing factor to

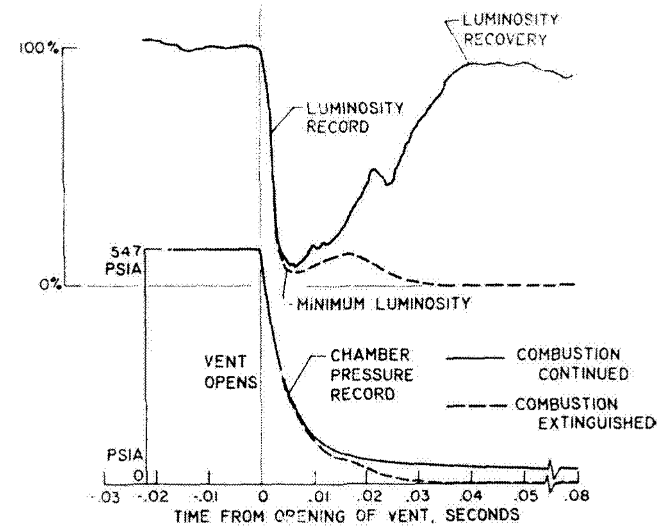

Fig. 2 Typical luminosity and chamber pressure transient records during rapid pressure decay

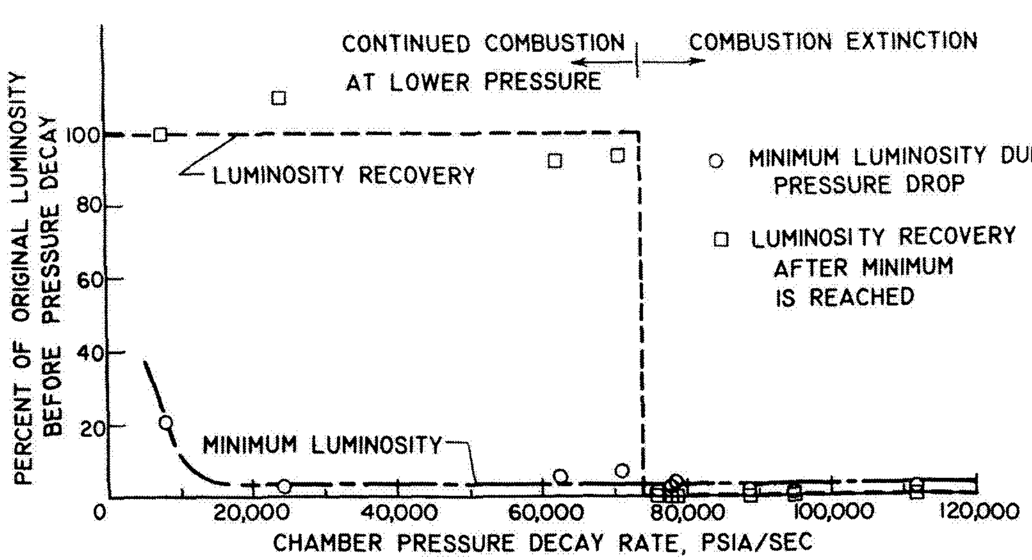

Fig. 3 Effect of chamber pressure decay rate on minimum combustion luminosity and luminosity recovery after pressure decay. Nominal chamber pressure, 540 psia

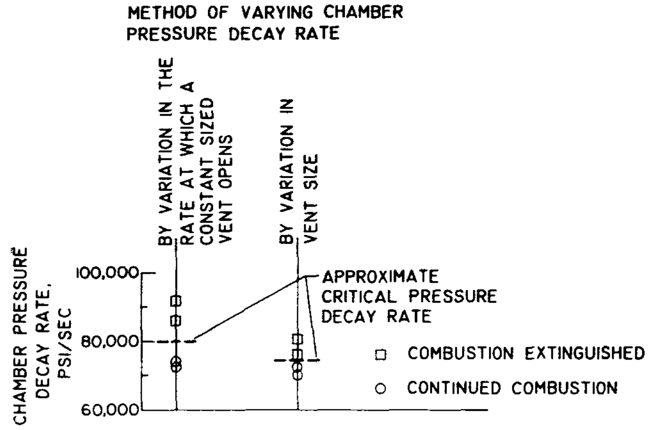

Fig. 4 Comparison of critical pressure decay rate obtained by two different methods. Nominal chamber pressure, 540 psia

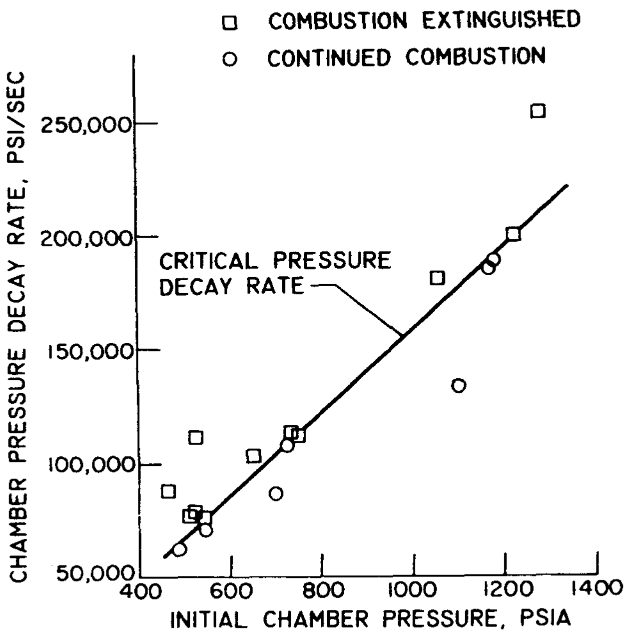

Fig. 5 Effect of initial chamber pressure on critical chamber decay rate

the combustion instability that is often encountered in solid propellant motors. During the expansion part of an instability wave the resulting reduction in flame intensity or reaction rate can act to amplify the pressure decrease.

Comparison of critical pressure decay rate obtained by two different methods

Variation in the chamber vent size varies not only the pressure decay rate but also the final chamber pressure. For example, as the vent size is increased, the pressure decay rate increases and final combustion pressure decreases, provided of course the combustion is not extinguished during the pressure drop. The pressure decay rate can be varied independently, however, by using a constant vent size and varying the rate at which the vent is opened. The pressure-time curves obtained by these techniques were quite similar in shape. A comparison of the critical pressure decay rate (minimum required to extinguish combustion) obtained by these two methods is shown in Fig. 4. Although there is some uncertainty as to the precise critical pressure decay rate because of the data spread, it appears as though the value is nearly the same in both cases. This indicates that the pressure decay rate was of primary importance in extinguishing combustion by sudden pressure decrease.

Combustion extinction as referred to in this article means a permanent termination of the combustion process. In all runs at an ambient pressure of 3.5 mm of mercury (equivalent to an altitude of 23 miles) in which the pressure decay rate was higher than critical, combustion was halted with no indication of any subsequent spontaneous reignition causing a low pressure burnout of the propellant. During some exploratory runs at ambient pressure about 700 mm of mercury, however, several instances were observed where the propellant reignited several seconds after combustion had apparently been completely extinguished. It appears that once combustion has been extinguished by a rapid pressure decrease, the propellant will not subsequently reignite in a low ambient pressure environment.

Effect of chamber pressure on critical decay rate

The variation of critical pressure decay rate (minimum required for combustion extinction) for a range of initial chamber pressures from 500 to 1200 psia is shown in Fig. 5. The chamber pressure decay rate was varied by varying the vent size. The circular and square symbols represent nonextinction and extinction points respectively. The line drawn between the extinction and nonextinction points represents the variation of critical chamber pressure decay rate with original chamber pressure level. The critical pressure decay rate was found to increase linearly as the chamber pressure level increased for the range of chamber pressure investigated. The critical pressure decay rate was approximately 74,000 psi/sec for an initial chamber pressure of 540 psia.

Summary of Results

The following summarizes the results of the initial phases of a study of the effect of rapid pressure decrease on combustion of an aluminized solid propellant.

1 There is a minimum rate of the decay of chamber pressure required to extinguish combustion. This minimum rate was 74,000 psia/sec for an initial chamber pressure of 540 psia.

2 Combustion luminosity measurements indicated that the flame was very sensitive to rapid pressure decrease, since it could be extinguished or quenched momentarily by pressure decay rates nearly an order of magnitude lower than required to extinguish the flame permanently.

3 The minimum pressure decay rate for extinction increased linearly as the chamber pressure increased.

References

1 Ciepluch, C. C., Allen, H., Jr. and Fletcher, E. A., "Ignition of Solid-Propellant Rocket Motors by Injection of Hypergolic Fluids," ARS Journal, vol. 30, no. 7, July 1960.

2 Price, E. W., "Analysis of Results of Combustion Instability Research on Solid Propellants," presented at the Solid Propellant Rocket Research Conf., Princeton, N. J., Jan. 28–29, 1960 (*ARS preprint no. 1068-60*).

3 Chaille, J. L. and Brown, L. M., Bulletin of the 13th Meeting of the Joint Army-Navy-Air Force Solid Propellant Group, June 4–6, 1957.